COMPARISON OF MEASURED DIRECT NORMAL RADIATION TO ESTIMATES MODELED FROM SATELLITE DATA

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ABSTRACT

Direct normal radiation is a key scientific parameter used by both the solar thermal electric and sustainable building design industries. As these industries mature, it has become increasingly important to determine the direct normal radiation (DNR) resource potential for many regions of the world. Although ground measurements of DNR are limited, satellite data can be used to calculate estimates of DNR where ground measurements do not exist by applying industry accepted conversion models. This paper presents the first results of applying the Perez model (Perez, et al., 1992) to calculate DNR using satellite-derived global horizontal irradiance estimates of the Surface meteorology and Solar Energy (SSE) data set. The results are compared to both Typical Meteorological Year based estimates and surface measurements for one site. Preliminary results show reasonable agreement between measured and SSE/Perez derived DNR during winter months. However, significant underestimation of DNR occurs during the summer months. Work is ongoing to determine the cause of these seasonal variations in SSE estimates of DNR using the Perez model.

1. INTRODUCTION AND BACKGROUND

1.1 The need for satellite-based DNR data sets

Direct normal radiation is a key scientific parameter used by both the solar thermal electric and sustainable building design industries. As these industries mature, it has become increasingly important to determine the direct normal radiation (DNR) resource potential for many regions of the world. Although ground measurements of DNR are limited, satellite data can be used to calculate estimates of DNR where ground measurements do not exist by applying industry accepted conversion models. The Perez model (Perez, et al., 1992) will be used for this preliminary study to determine the accuracy and feasibility of using satellite data to derive DNR.

Historically, climatological profiles of insolation and meteorology parameters calculated from ground measurement data have been used successfully for resource assessment in the renewable energy industry. However, there are inherent problems in using ground measurements for resource assessment. Although ground measurement stations are located throughout the world, they are situated mainly in populated areas and therefore do not provide adequate estimates of insolation and meteorology parameters on a global basis. Also, at any particular station, data recording can be sporadic leading to incomplete climatological profiles. And finally, data inconsistencies (due to variable quality control procedures) can occur within a station and from one station to another.

1.2 Surface meteorology and Solar Energy Data Set

In contrast to ground measurement data, satellite-derived data sets have the advantage of containing estimates of DNR with spatial uniformity for long-time periods to complement ground measurements. A satellite-derived data set with the potential to produce DNR estimates is the Surface meteorology and Solar Energy Data Set (SSE). The SSE data set was generated by NASA's Earth Science Enterprise Surface meteorology and Solar Energy commercial outreach project which strives to make resource assessment data available to the renewable energy industry by way of the Internet. This data set is a satellite-derived 10-year climatology (1983- 1993) of global insolation, cloud cover, temperature, surface pressure, surface reflectance, relative humidity, and wind parameters.

The SSE data set is a continuous 10-year global climatology of insolation and meteorology data on a 2.5^o equal-area grid system. Although the SSE data within a particular grid cell are not necessarily representative of a particular microclimate, or point, within the cell; the data are considered to be the average over the entire region of the cell. For this reason, the SSE data set is not intended to replace ground measurement data. Its purpose is to fill the gap where ground measurements do not exist, and to augment data where ground measurements do exist. Comparisons have shown that SSE estimates of global horizontal radiation have bias differences less than 2% and RMS uncertainties less than 14% when monthly values of global horizontal radiation are compared with historic ground site measurements of the World Radiation Data Base (Whitlock et al., 2000). This paper explores extending this data set to include estimates of DNR.

2. DATA AND METHODS OF COMPUTATION

2.1 Data Sources

Three data sources have been used in this study: SSE 3-hourly cloud and global horizontal irradiance data, the National Renewable Energy Laboratory's (NREL) Typical Meteorological Year (TMY) data set of monthly averages of direct normal irradiance, and hourly ground measurements of direct normal irradiance at Kramer Junction, CA.

The SSE 3-hourly global horizontal irradiance and cloud data are derived from the International Satellite Cloud Climatology Project (ISCCP) D1 data set. ISCCP D1 provides global coverage of satellite data on an equal-area grid. Each grid cell represents an area equal to that of a 2.5^o by 2.5^o latitude/longitude grid cell at the equator (280 km x 280 km). Using ISCCP D1 data as input, 3-hourly global horizontal irradiance data is calculated from a shortwave model developed by Dr. Rachael Pinker and Dr. Istvan Laszlo of the University of Maryland. The Pinker/Laszlo model is a physical model based on radiative transfer calculations using the delta-Eddington approximation (Pinker and Laszlo, 1992). As stated in section 1.2, both the global horizontal irradiance and cloud fraction data used in this study are representative of the entire cell in which a site resides and may not be a true indicator of a site's actual irradiance measurements or overhead cloud cover.

DNR provided for fifty-two primary stations from the NREL TMY data set are used for comparison to DNR estimated from SSE global horizontal irradiance. These stations are National Weather Service stations that collected meteorological data for the period 1961 – 1990. The primary stations measured solar radiation from 1 to 27 years of the measurement period (Marion and Urban, 1995). Comparisons to TMY stations are made on a seasonal basis using 1986 ISCCP D1 data. This year can be considered a near average meteorological year, having only a slight influence of El Nino weather fluctuations.

KJC Operating Company provided the hourly ground measurement data used in this study. The measurement site is located at 35^o 01' 01'' N. Latitude 117^o 33' 24'' W. Longitude and resides in the southwest corner of an ISCCP grid cell. The altitude of the site is 2640 ft. The year 1992 was used for this study.

2.2 The Perez Method and Interpolation Procedure

The Perez model consists of a set of linear equations derived statistically from a multi-climatic ground measurement data set (Perez, et al., 1992). In estimating direct beam irradiance, the Perez model requires hourly input data for global horizontal irradiance, solar zenith angle, Julian day, and altitude. Dew point temperature is optional input to the model and was not used for our calculations. As stated previously, satellite-derived estimates of irradiance and meteorology values are provided on a 3-hourly basis. Three basic interpolation schemes were tested for deriving hourly input to the Perez model. The procedure used for the comparisons in this paper analytically calculated the solar zenith angle at each hour and linearly interpolated the irradiance values between the 3-hourly measurements. Cloud cover data was also analyzed for estimating maximums in irradiance values that could potentially occur near solar noon. If ISCCP D1 cloud cover was less than 20% for the nearest measurements prior to- and following- solar noon and an irradiance measurement did not exist at solar noon, then irradiance values were extrapolated out to solar noon.

3. RESULTS

The year 1992 was processed for the ISCCP D1 cell containing the Kramer Junction, CA site. Results are provided in Table 1. The percent differences shown for January through May and the months of November and December are reasonable, within 30%, and can be expected due to the meteorological variations which would occur when comparing site data to a satellite-derived data set encompassing a much larger region. However, significant differences occur over the rest of the year. Satellite-derived values of monthly cloud cover, monthly cloud optical depth, and the number of clear-sky days over the month were reviewed for possible correlations. However, no significant dependencies were found. One possible explanation for the breakdown in correlation over the summer months is the difficulty of satellite-derived estimates to accurately portray the variable cloud patterns that occur during the day due to summertime heating at point locations.

TABLE 1: COMPARISON OF MEASURED DATA AT KRAMER JUNCTION, CA TO MODELED DATA USING THE PEREZ METHOD FOR 1992

Month	Measured	Modeled	% Difference
January	4.73	4.66	-1.69
February	4.29	3.64	-15.15
March	3.87	3.67	-5.17
April	6.67	5.64	-15.44
May	6.93	4.83	-30.30
June	8.68	5.18	-40.32
July	8.55	3.99	-53.33
August	8.09	3.70	-54.26
September	7.52	3.72	-50.53
October	6.11	3.33	-45.50
November	5.99	4.31	-28.05
December	4.44	3.65	-17.80

Figures 1 & 2 show comparisons of best and worst case estimates of DNR using the Perez method to TMY ground measurement data for January and July. The year 1986 was used for comparison purposes to the TMY data set. This year can be considered a near-average meteorological year with only a slight influence of El Nino weather fluctuations. These results are consistent with that of Table 1. Although January represents a good correlation, July shows a breakdown of one-to-one correspondence resulting in large scatter.

Figures 3 and 4 show maps of the US comparing the NREL TMY data set to SSE/Perez estimates of DNR. For consistency, the year 1986 was used for comparison to the TMY data set. As expected, based on previous results comparing individual ground measurement stations to SSE/Perez estimates, only the data for January shows a correlation.

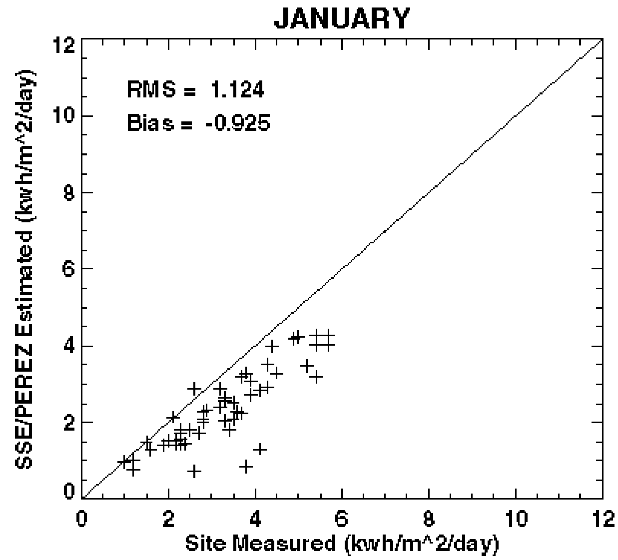

Figure 1: Comparison of TMY site measurements of DNR to SSE/Perez estimates for January.

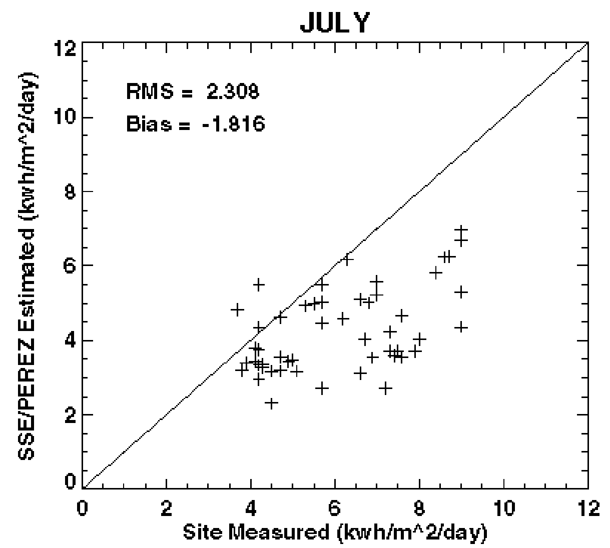

Figure 2: Comparison of TMY site measurements of DNR to SSE/Perez estimates for July.

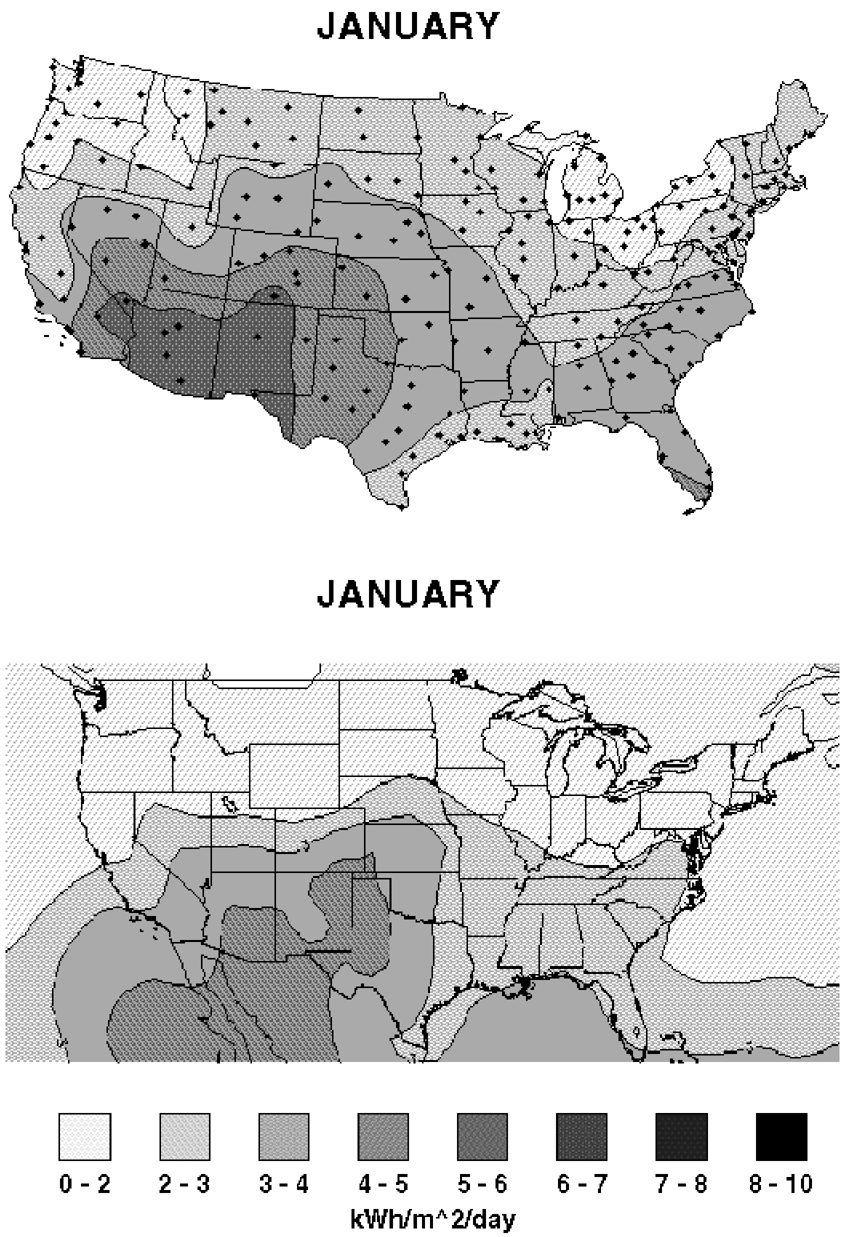

Figure 3. Comparison of TMY Measured and SSE/Perez Estimates of DNR for January.
Top: NREL/TMY
Bottom: SSE/Perez

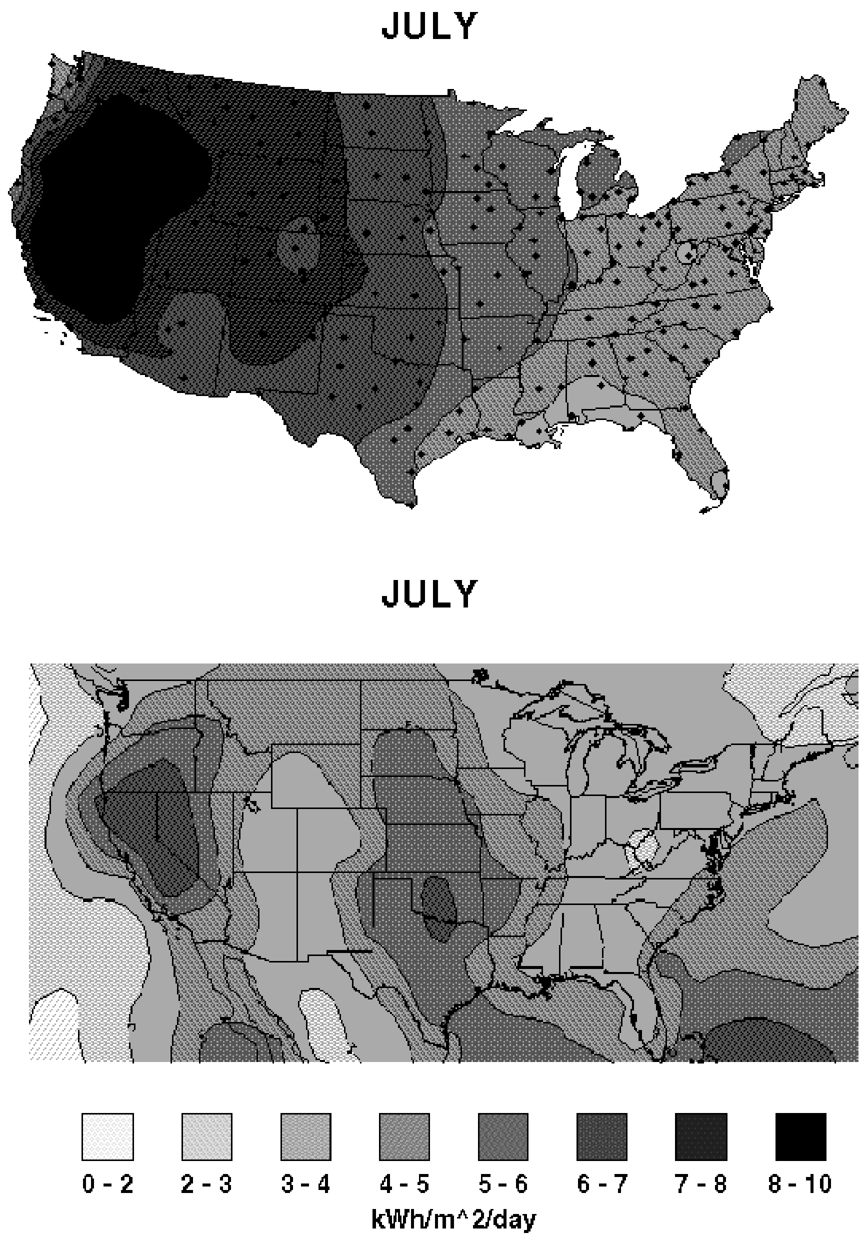

Figure 4. Comparison of TMY Measured and SSE/Perez Estimates of DNR for July.
Top: NREL/TMY
Bottom: SSE/Perez

4. CONCLUDING REMARKS

This paper presents preliminary results for estimating DNR from the SSE satellite-derived data set using the Perez model. Monthly comparisons to both a single site and the TMY data set show reasonable agreement during winter months. However, a breakdown of one-to-one correspondence occurs during summer months. Analysis of satellite-derived cloud cover, cloud optical depth, and the number of clear sky days reveal no significant dependencies on the results. Work is ongoing to determine the cause of the seasonal variations.

5. REFERENCES

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